Invention and Initial Development of Monopulse Radar

Story of Monopulse Tracking Radar

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The invention of search radar soon led to the development of target tracking radar needed for gun fire control. The first tracking radars used a narrow beam that was either conically scanned or sequentially lobed around the target to accurately sense the target displacement from the antenna axis by observing the target echo amplitude during a scan or lobing cycle. The tracking usually provided the high accuracy target tracking that was needed for gun fire control during World War II, but they were vulnerable to receiver noise and undesired target echo amplitude fluctuations that occur during a beam scan or lobing cycle. Random target echo fluctuation and receiver noise diluted the tracking accuracy and periodic echo fluctuation such as that caused by a target's propeller or jet aircraft turbine blades could cause severe tracking errors.

Robert M. Page at NRL studied means for reducing or avoiding this vulnerability and devised a technique for providing multiple lobes about the antenna axis that could be compared simultaneously to sense target displacement from the axis (boresight) of the antenna.1 This technique called "Simultaneous Lobe Comparison, Pulse Echo Location System" invented and documented in 1943 and patented by Page under Patent No. 2,929,056 filed on 11/5/1947 but was not published until 3/15/1968 because of security consideration. This technique was later given the more convenient name "monopulse tracking radar" even though it did not need pulse operation and performed equally effectively with CW radiation.

The construction of the experimental monopulse tracking radar required considerable ingenuity and innovation especially for design of the original four-horn microwave feed with microwave circuitry that could take the sum and difference of the receive signals from the top and bottom pairs for elevation angle error sensing, right and left pairs of horns for azimuth angle error sensing, and the sum of all four horns for detection and tracking in range. Few microwave components were available in the 1940's and this signal processing was done with ring hybrids (rat races) that could be milled from a block of aluminum in the NRL machine shop. The original feed details, seen in Figure 1, were designed by Harry L. Gerwin of NRL and included an arrangement of waveguide twists that caused the angle sensing signals to be generated by symmetrical signal paths through the ring hybrids to maximize bandwidth and accuracy of angle error sensing.

The original experimental X-band monopulse radar (Figure 2) used a metal plate lens, because of the size and weight of the original feed, to avoid signal blockage of a focal point parabolic antenna and place the feed near the axis of rotation of the antenna pedestal. It was originally designated the Mk 50 but also called the TAB radar (BAT spelled backwards). It included a boresight telescope with a movie camera on top to record the target angular location, relative to the antenna boresight, observed optically with cross hairs. It was installed on a building roof top at NRL where it could be conveniently observed, by looking down the Potomac River, for experimental tracking of aircraft flying up the river to measure its performance. The experimental radar was provided with two monopulse receiving systems to allow skin tracking of the aircraft by one receiver and a reference tracking of a time delayed beacon pulse repeater on the aircraft. This allowed the radar to separately track the aircraft echo pulse and the delayed beacon pulse. The monopulse skin angle tracking was recorded relative to the reference point source location of the beacon. The resulting monopulse accuracy measurements were performed by the NRL Tracking Radar Branch under John E. Meade and his Section Head, Bernard L. Lewis, and successfully demonstrated the monopulse radar precision. The experiments at NRL ceased in the late 1970's because of interference with the Washington National Airport (now Regan National Airport) radars.

The expected immunity from echo amplitude fluctuation was confirmed; however, the measurements led to the discovery of an additional source of radar angle tracking error resulting from interference of the echo pulses from the multiple reflectors of an aircraft. This unexpected source of was especially significant because it could cause the apparent angular location of a complex target to fall beyond the physical extent of the target. Meade demonstrated this phenomenon theoretically assuming a two reflector target. This error source was a fundamental phenomenon that is well known for causing severe angle tracking errors when tracking low altitude targets over the sea with interference from its reflected image. The phenomenon was exploited as the Cross-Eye Countermeasure patented as "Security Device," NRL Patent No. 4,006,478 by B. L. Lewis and D. D. Howard, filed 8/15/1958 and published 2/01/1977. The phenomenon was also shown by Lewis and Howard to be a fundamental error caused by echo signal phase front distortion that can affect any radar system but significant for mainly high precision tracking radars.3

One of the first operational applications of monopulse with a metal plate antenna was the missile guidance radar for the Western Electric Nike-Ajax missile system, an early continental air defense weapon. The missile sites were deployed to many locations throughout the country with several in the vicinity of Washington, D. C. in the 1940's.

The first major advancement to very high precision tracking was made by David K. Barton and his group at the RCA Plant in Moorestown, N. J. (now Lockheed Martin Plant). This group produced the C-band AN/FPS-16 precision tracking radar in the 1950's to meet the stringent range safety accuracy requirements by NASA and the U.S. Air Force for missile launches of the NASA manned space program. Barton and his group produced a compact monopulse radar feed that could be used at the focal point of a parabola dish antenna and a high precision servo pedestal with rapid servo response. The radar provided position data from point-source targets with azimuth and elevation errors of less that 0.1 milliradians (approximately 0.006 degrees) and range errors of less than 5 yards with a signal-to-noise ratio of 20 decibels or greater. The Air Force experimented with high precision trilateration techniques for the task that performed well, but the separated signal source sites of a trilateration system were vulnerable to slight shifts in their relative elevations that resulted from the ocean tide changes in the vicinity of the launch sites. This caused unacceptable drift in their calibration resulting on the selection of the RCA AN/FPS-16 for the range safety task.

The proliferation of new applications and designs of monopulse radar has led to a wide diversity of forms of the technique, all based on the fundamental principle of comparison of signals received simultaneously by different antenna patterns to provide the needed high precision capability of radar. RCA continued the development of many instrumentation radars for a many missile range applications. This included the very high precision AN/FPQ-6 29 ft C-band radar with an angle precision of 0.05 milliradians and range precision of 2 yards in use in the U. S. space program. RCA also developed monopulse phased arrays to meet demands for simultaneous multi-target tracking both for instrumentation for missile ranges and tactical radars. The multi-target instrumentation radar, AN/MPS-39, originally designed by RCA and further developed by Lockheed Martin (at the once RCA Plant, Moorestown N. J.) is actively used at the White Sands Missile Range. The AN/SPY-1 monopulse phased array tactical radar, initially developed by RCA, is deployed in the Navy's guided missile cruisers and destroyers.

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References

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Figure 1 Original Monopulse Radar Four Horn Feed